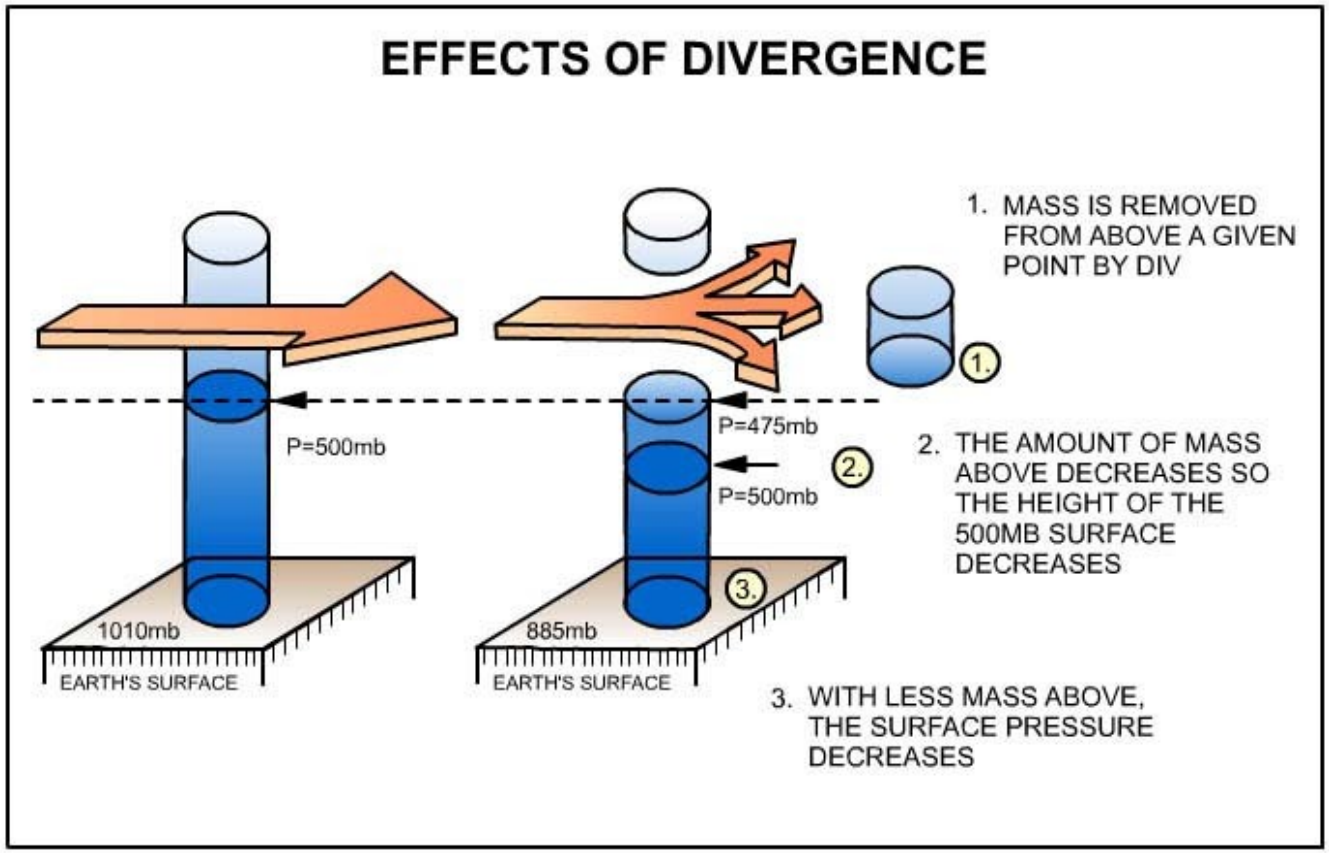
Atmospheric Dynamics I

c. Determine kinematic processes which describe divergence in the wind flow.

Divergence (DIV- Speed, Directional or both)

- Measure of the rate of **net removal** of mass out of a volume of air above a given point.
- Results in a decrease of atmospheric mass **above** a given point in the atmosphere.

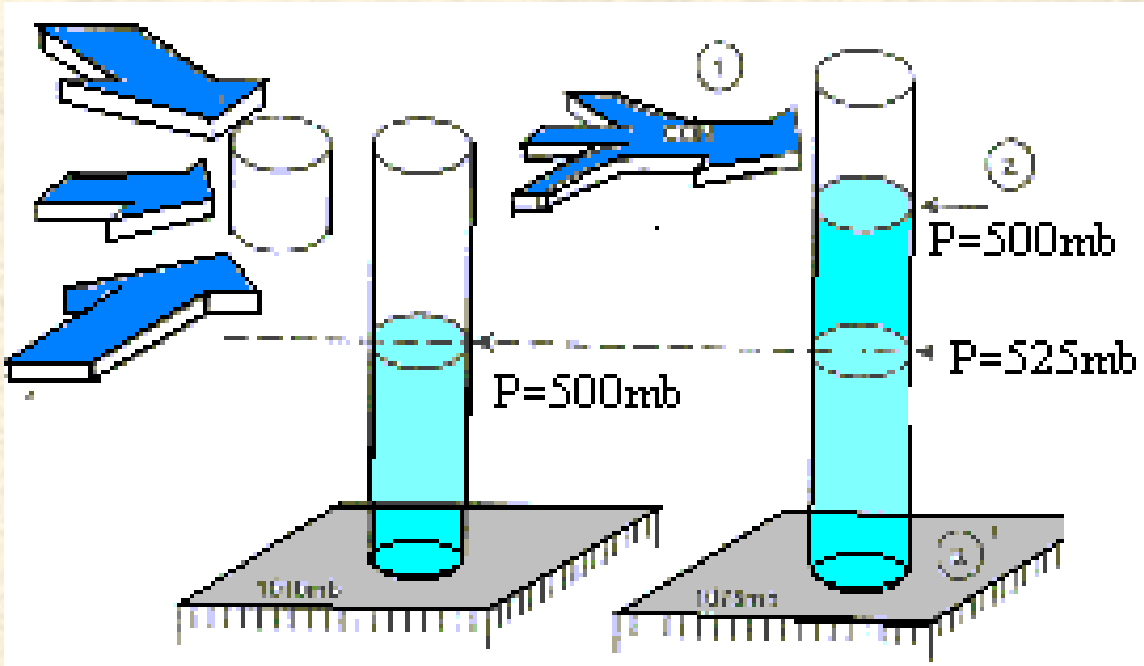
Effects of Divergence



Convergence (CONV - Speed, Directional or both)

- Measure of the rate of the **net addition** of mass into a volume above a given point.
- Results in an increase of atmospheric mass **above** a given point.

Effects of Convergence



1. MASS IS ADDEDABOVE A GIVEN POINT BY CONVERGENCE
2. THE AMOUNT OF MASS ABOVE INCREASES SO THE HEIGHT OF THE 500MB SFC INCREASESS
3. WITH MORE MASS ABOVE, THE SURFACE PRESSURE RISES

Divergence Equation in Natural Coordinates (Horizontal Only)

$$DIV_H = \frac{\Delta V}{\Delta s} + \frac{V \Delta \alpha}{\Delta n}$$

(A) **(B)**

Divergence Equation in Natural Coordinates

$$DIV_H = \frac{\Delta V}{\Delta s} + \boxed{\frac{V\Delta\alpha}{\Delta n}}$$

(A) **(B)**

Divergence Equation in Natural Coordinates

In Term B,

- V is the wind speed and is always a positive value.
- $\Delta\alpha$ is the angle of change in the wind direction across the flow in the $+\Delta n$ direction (i.e. Δn is positive in the direction to the left of the wind flow.

  $\Rightarrow$Winds backing along $+\Delta n$ (I.e. turning in a counter-clockwise direction along $+\Delta n$) produce a “positive” change in $\Delta\alpha$ (I.e. $\Delta\alpha$ is “positive”)

Divergence Equation in Natural Coordinates

⇒ Winds veering along $+\Delta n$ (i.e. turning in a clockwise direction along $+\Delta n$) produce a "negative" change in $\Delta\alpha$ (I.e. $\Delta\alpha$ is "negative")

- Δn = distance in the $+\Delta n$

(i.e. $[n_{\text{left of flow}} - n_{\text{right of flow}}]$)

$$DIV_H = \frac{\Delta V}{\Delta s} + \frac{V\Delta\alpha}{\Delta n}$$

Divergence Equation in Natural Coordinates

$$DIV_H = \frac{\Delta V}{\Delta s} + \frac{V\Delta\alpha}{\Delta n}$$

(A) **(B)**

- Term A (Speed Divergence/Convergence)
  - Speed divergence
    - Caused by winds rapidly increasing speed downstream. Thus,

$\forall \frac{\Delta V}{\Delta s} = (V_{downstream} - V_{upstream}) = (larger - smaller)$

$= (\frac{+}{+}) = +$

$(s_{downstream} - s_{upstream})$ (larger - smaller)

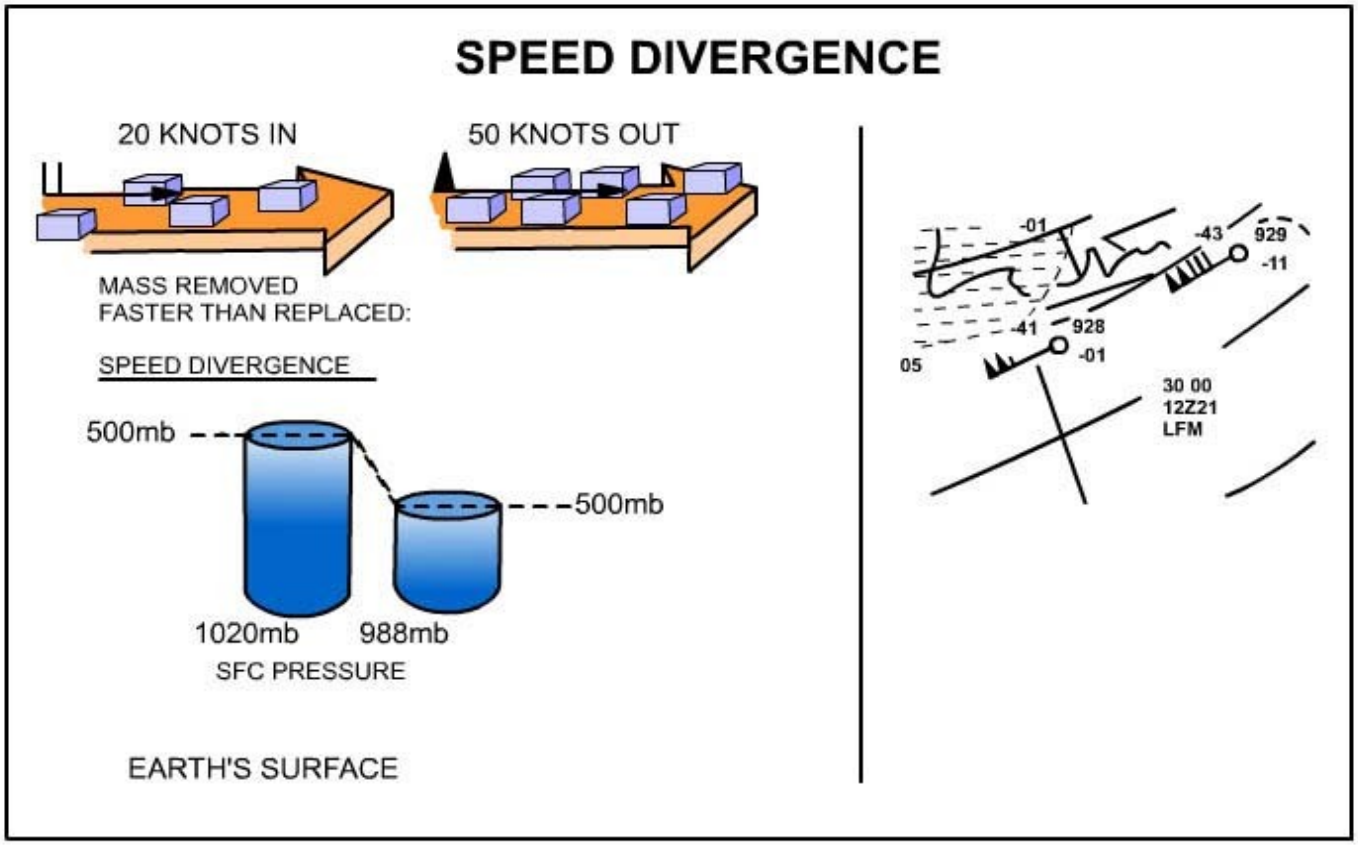
(+)

Divergence Equation in Natural Coordinates

- Higher speed winds upstream pull mass out of area faster than it can be replaced by slower speed winds, thus ideally decreasing the mass.

- In PPT example, mass is being removed from the hatched area. (NOTE: These are subjective analyses)

Speed Divergence



Determine the kinematic processes which describe divergence October 20

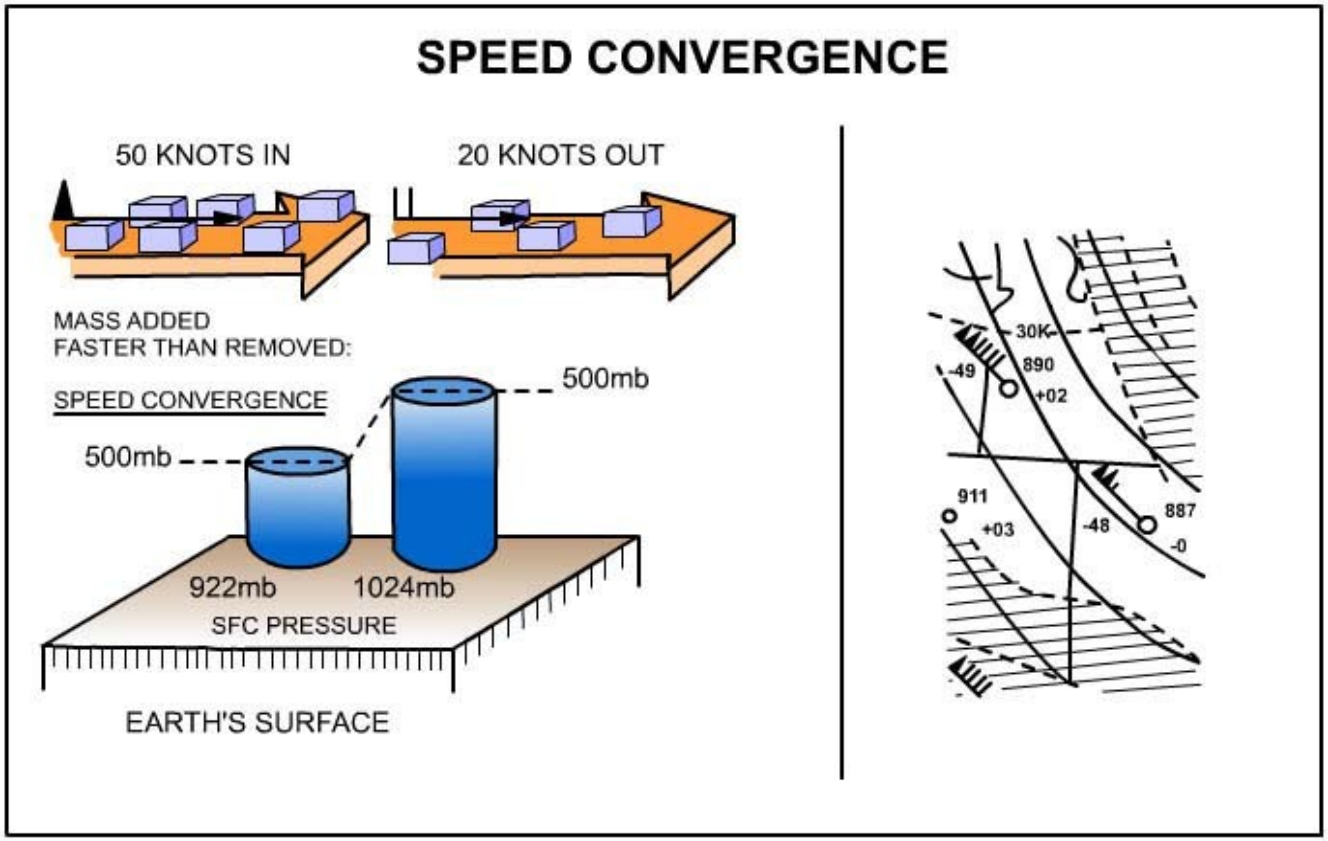
Divergence Equation in Natural Coordinates

- Speed convergence
  - Caused by winds rapidly decreasing speed downstream. Thus,

$\forall \frac{\Delta V}{\Delta s} = \frac{(V_{downstream} - V_{upstream})}{(s_{downstream} - s_{upstream})} = \frac{(\text{smaller - larger})}{(\text{larger - smaller})} = (-) = -$ (+)

  - Higher speed winds upstream push mass into an area faster than it can be removed by the slower speed winds downstream, thus increasing the mass.
  - In PPT example mass is being added to the hatched area.

Speed Convergence



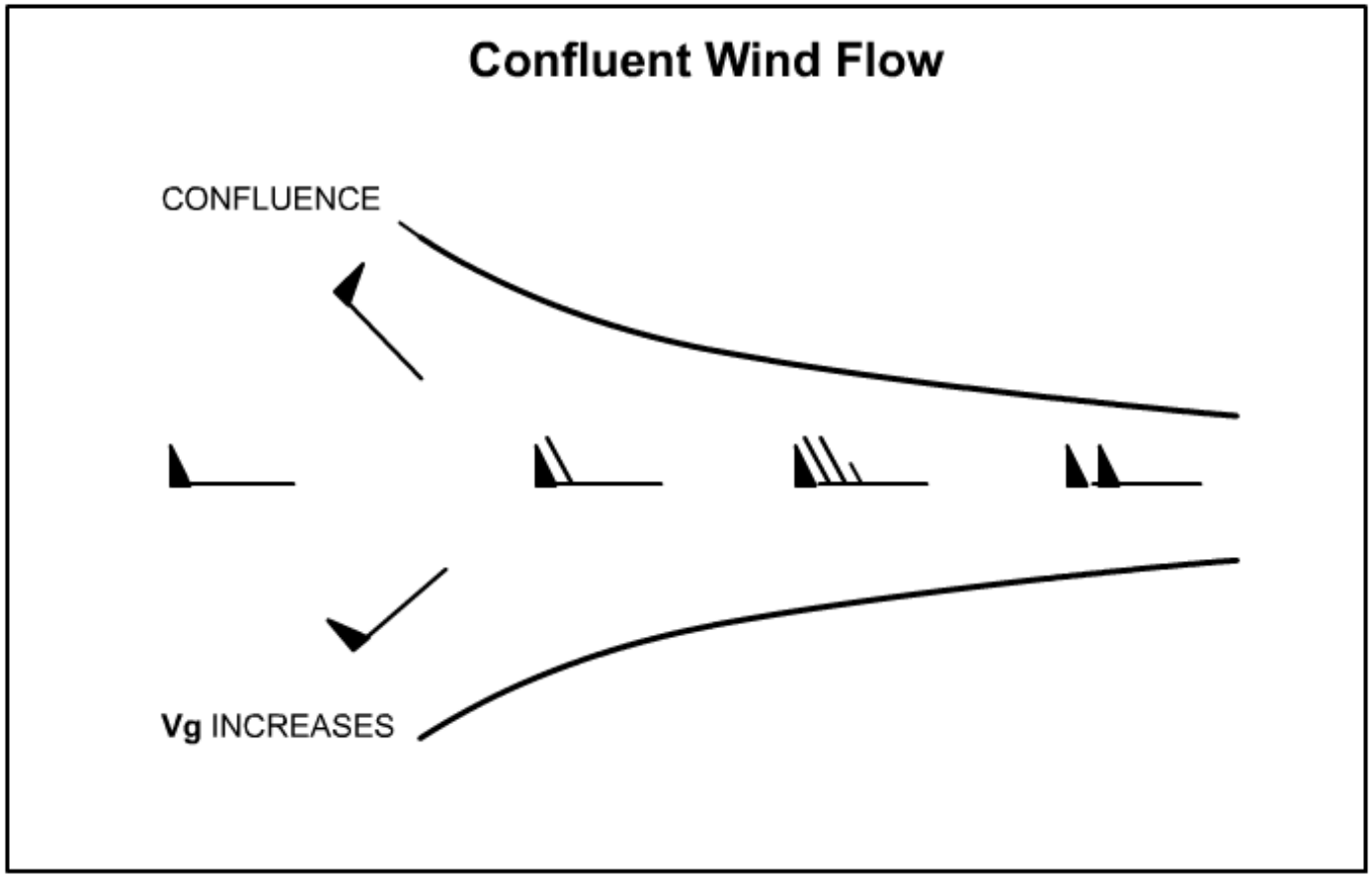
Divergence Equation in Natural Coordinates

$$DIV_H = \frac{\Delta V}{\Delta s} + \boxed{\frac{V\Delta\alpha}{\Delta n}}$$

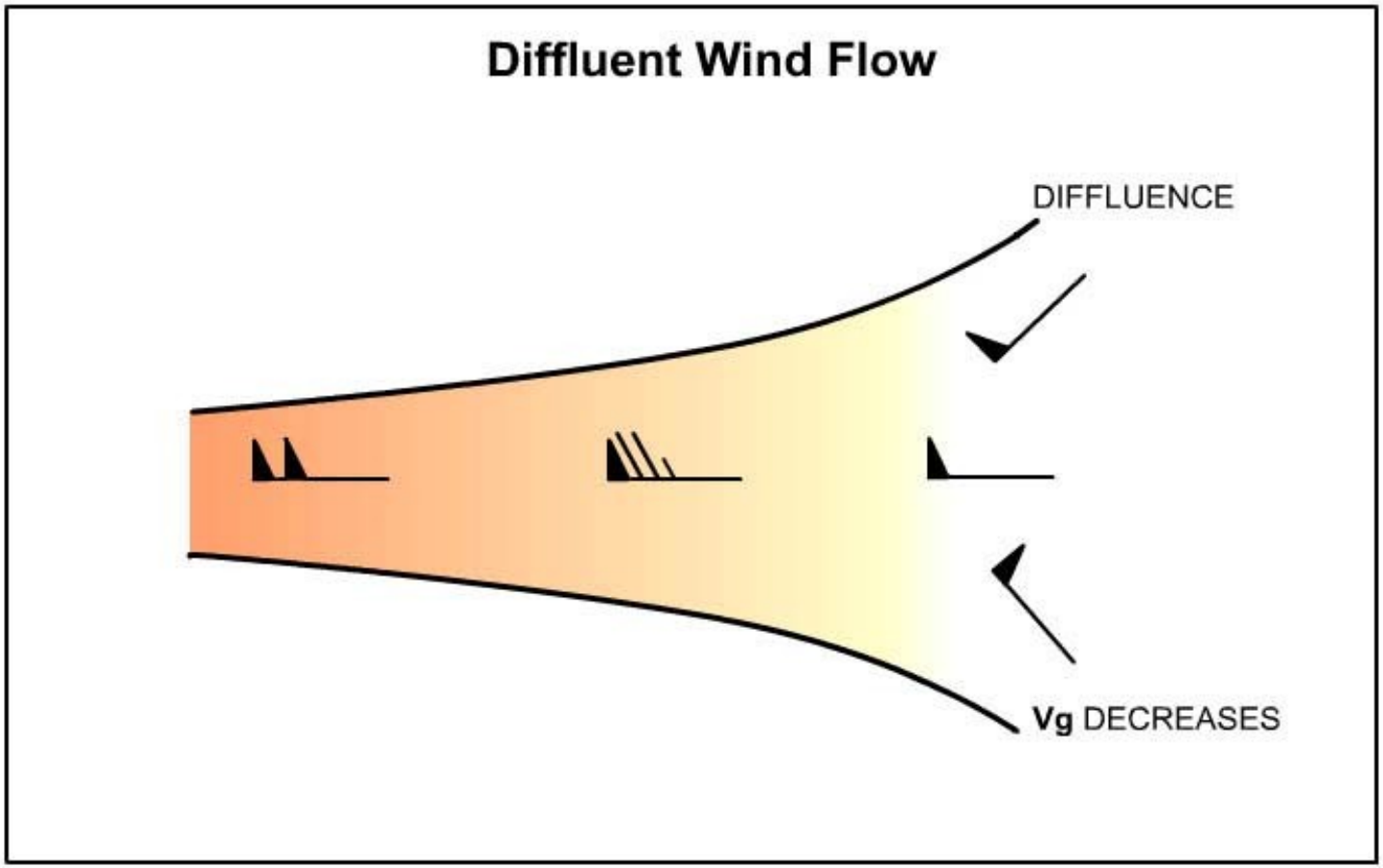
(A) **(B)**

- Term B (Directional divergence/convergence)
  - Confluence -The merging of wind flow into a common axis.
  - Diffluence – The spreading apart of wind flow from a common axis

Confluent wind flow



Diffluent wind flow



Divergence Equation in Natural Coordinates

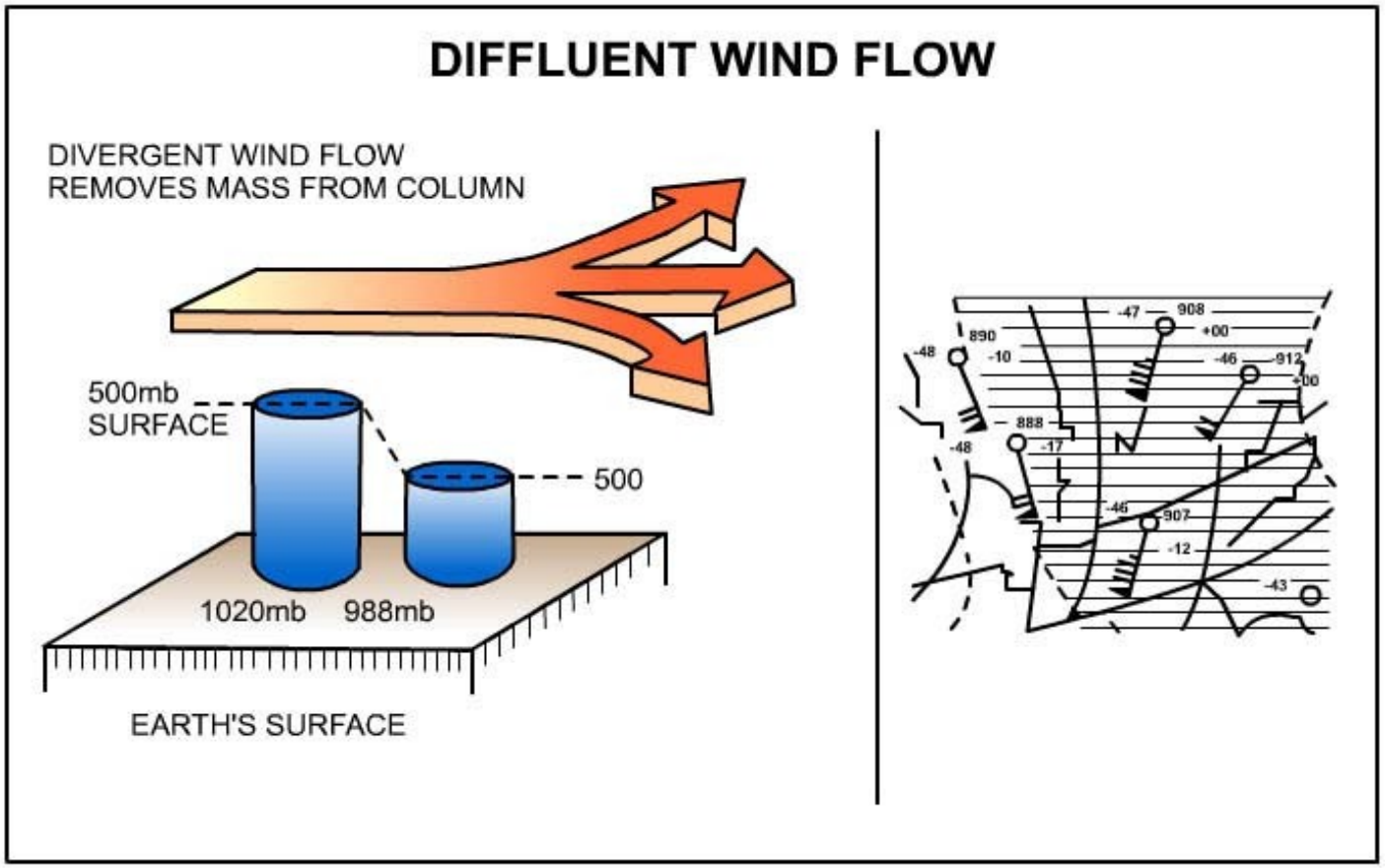
- Diffluence
  - Spreading or fanning out of wind flow or contours.

- $V \underline{\Delta\alpha} = V (\underline{\alpha_{\text{left of flow}} - \alpha_{\text{right of flow}}}) = + (\underline{\text{larger - smaller}}) = + (\underline{+}) = +$

  $\Delta n \qquad (n_{\text{left of flow}} - n_{\text{right of flow}}) \qquad (\text{larger} - \text{smaller}) \qquad (+)$

  - May result in mass being removed from the area of diffluent flow.
  - In PPT example this is occurring below the hatched area.

Diffluent wind flow



Divergence Equation in Natural Coordinates

– Confluence

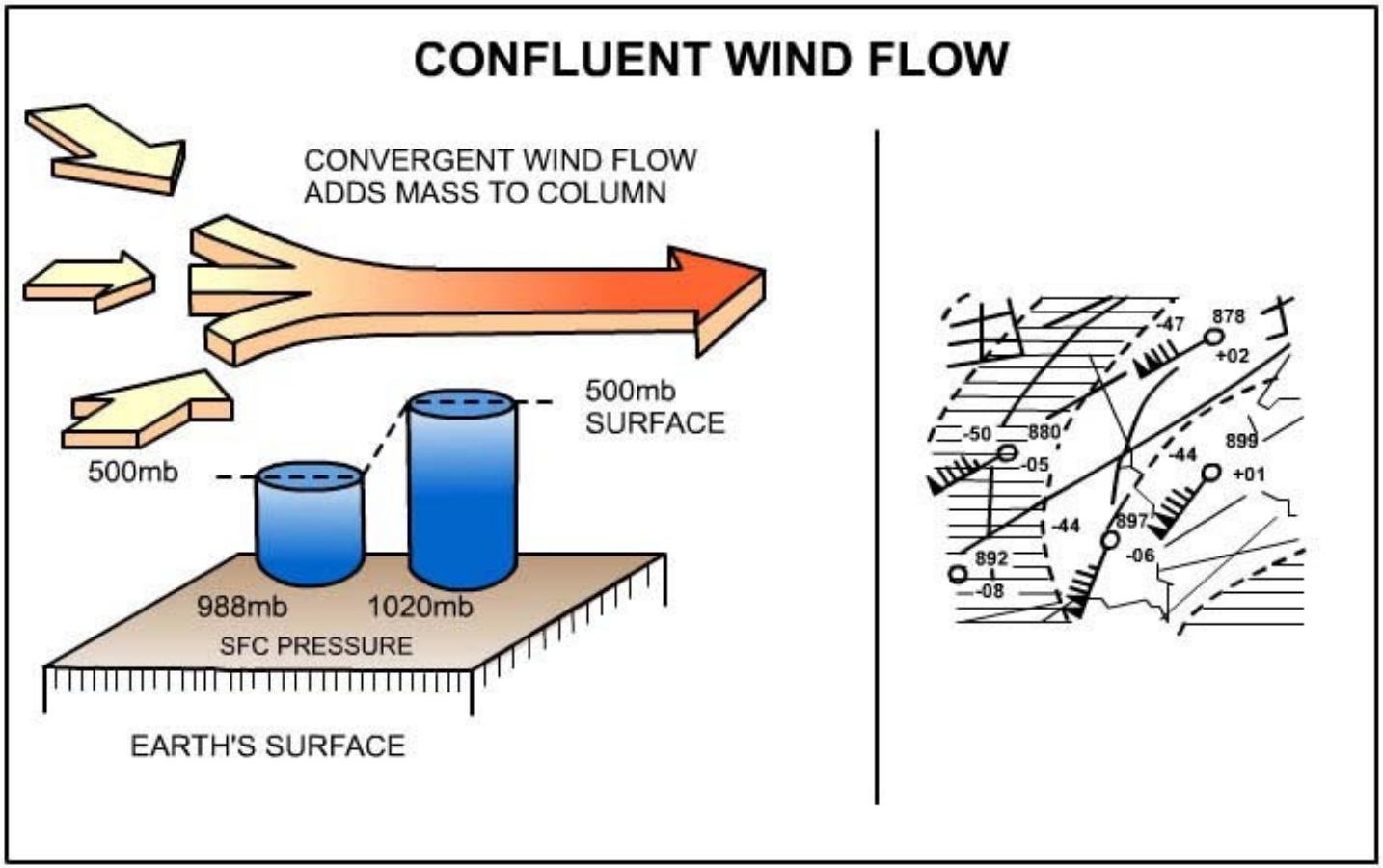
- Merging of wind flow or contours.

- $V \underline{\Delta\alpha} = V (\underline{\alpha_{\text{left of flow}} - \alpha_{\text{right of flow}}}) = + (\underline{\text{smaller - larger}}) = + (\underline{-}) = -$

  Δn $(n_{\text{left of flow}} - n_{\text{right of flow}})$ (larger – smaller) (+)

- May result in mass being added to the area of the confluent flow.
- In PPT example this is occurring in the hatched area.

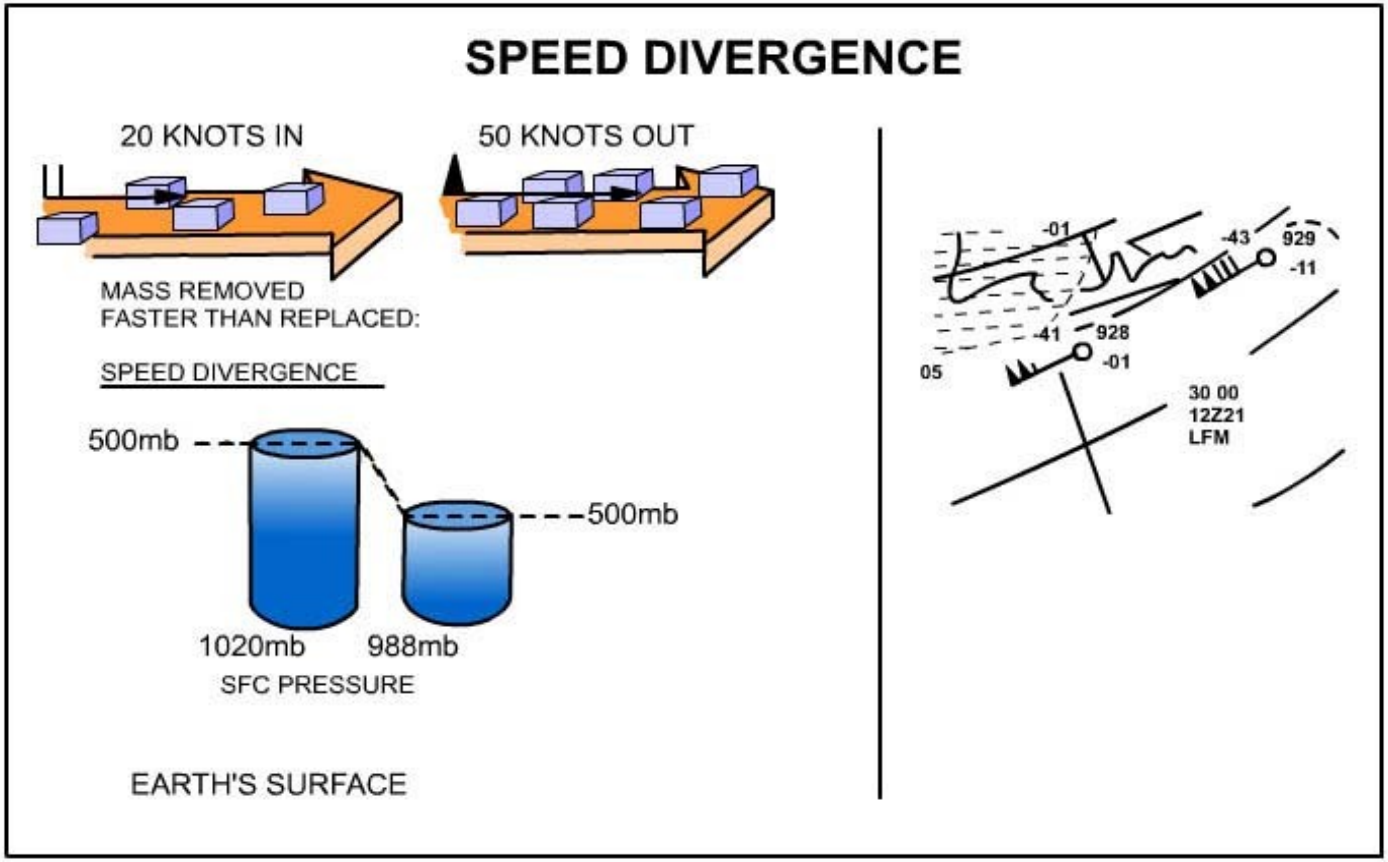
Confluent wind flow



Divergence Equation in Natural Coordinates

- **Wind Speed**
  - **Speed divergence**
    - **Caused by winds rapidly increasing speed downstream.**
    - **Higher speed winds pull mass out of area faster than it can be replaced by slower speed winds, thus ideally decreasing the mass.**

Speed Divergence

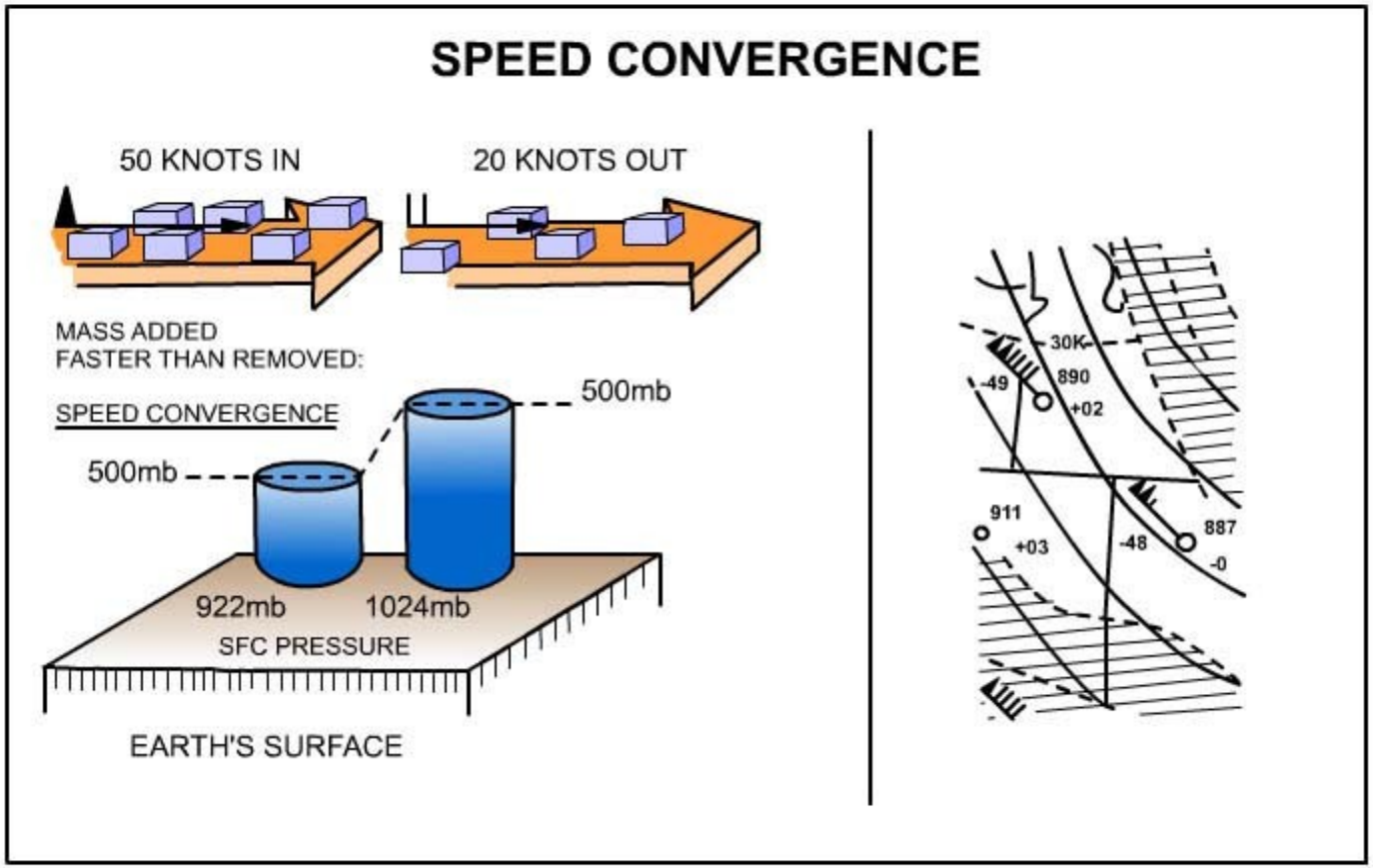


Determine the kinematic processes which describe divergence October 20

Divergence Equation in Natural Coordinates

- **Speed convergence**
  - **Caused by winds rapidly decreasing speed downstream.**
  - **Higher speed winds push mass into an area faster than it can be removed by the slower speed winds, thus increasing the mass.**

Speed Convergence

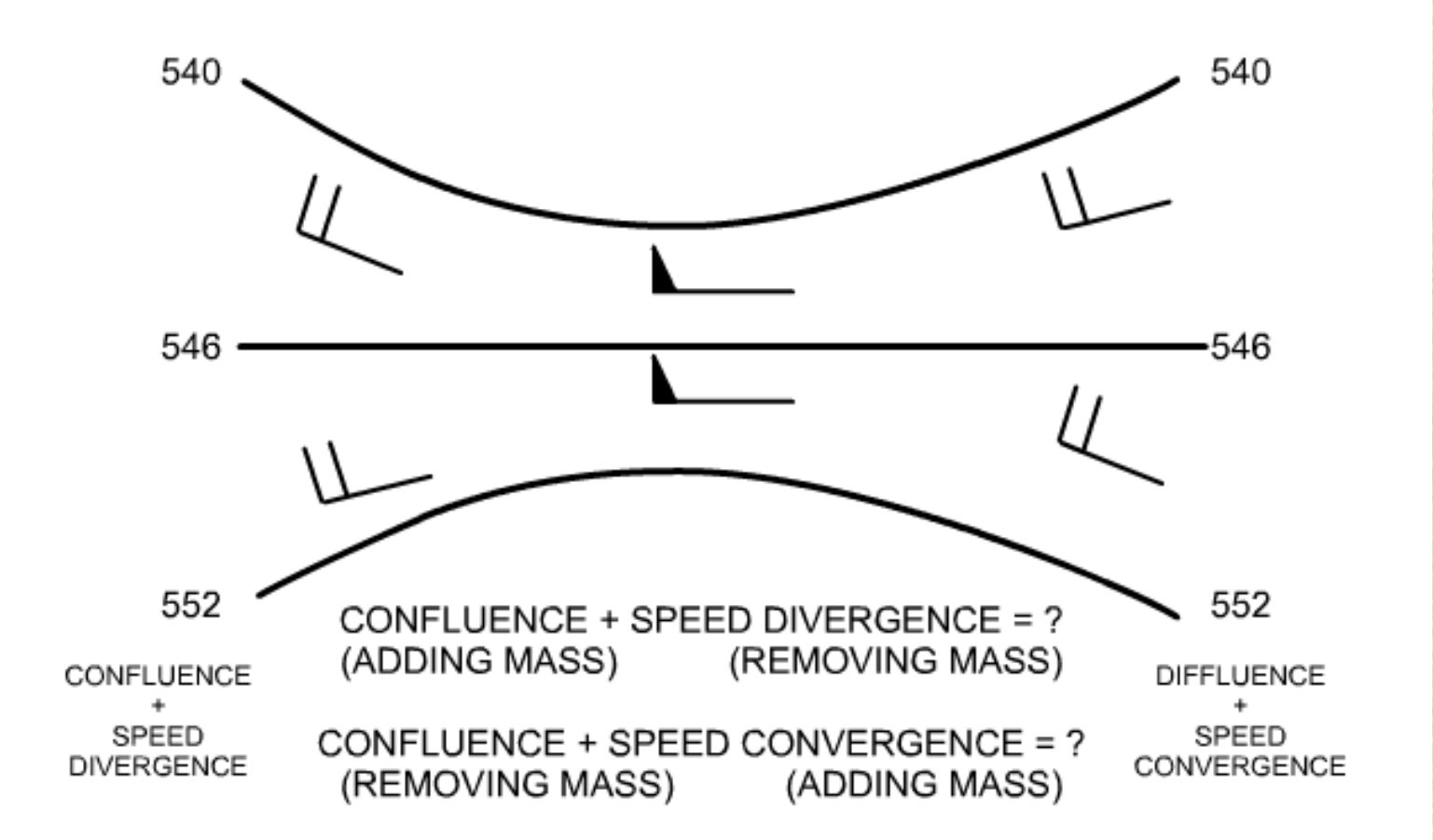


Divergence Equation in Natural Coordinates

- **Direction and speed tend to offset each other on constant pressure charts.**

- Note that speed and direction can either complement or oppose one another, thus, a positive Term A (speed divergence) may be opposed by a negative Term B (confluence).

Opposing effects of speed and direction



Divergence Equation in Natural Coordinates

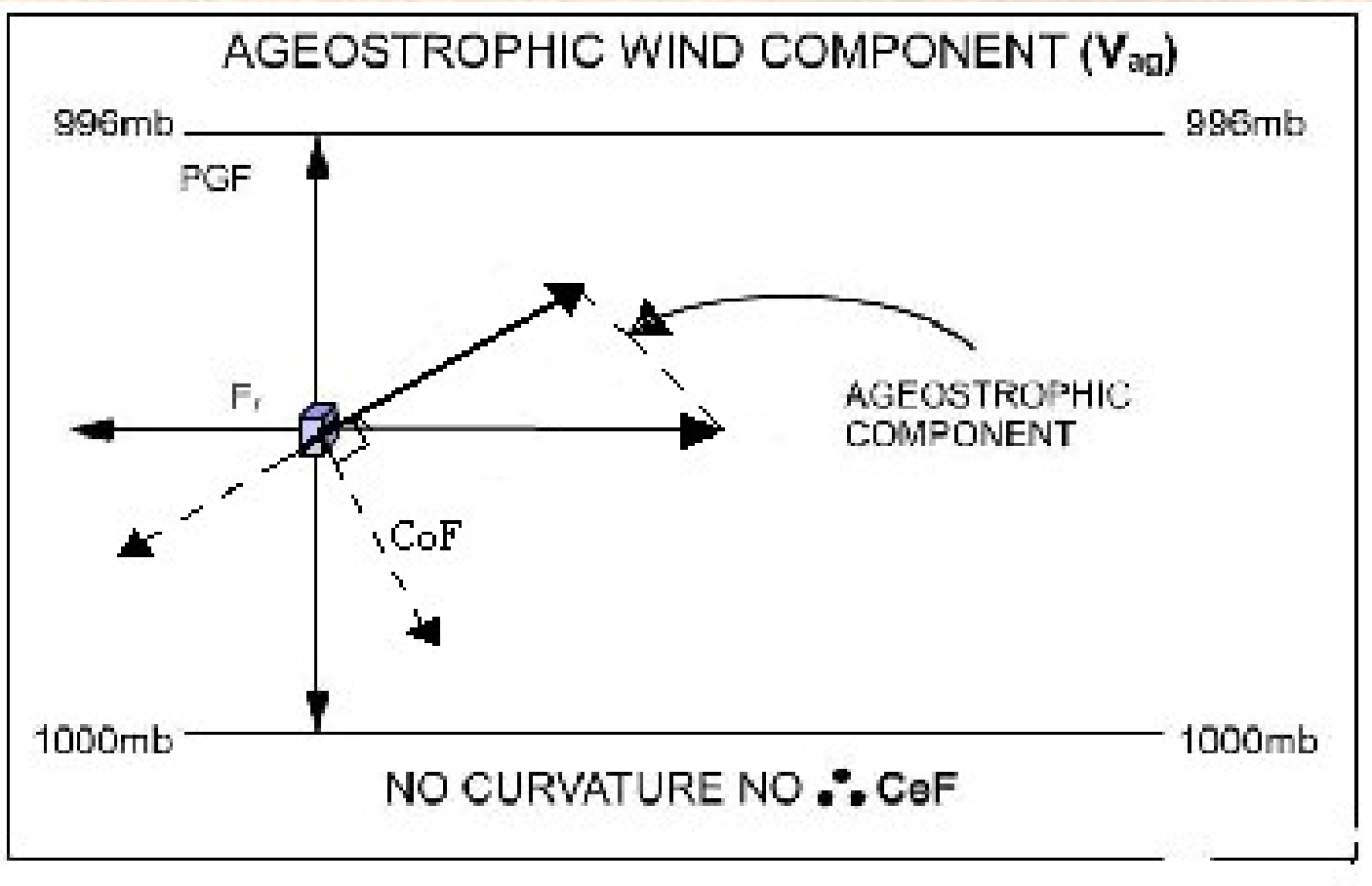
- Vorticity charts and vertical motion charts can tell you if net divergence or convergence is occurring aloft.

- But sometimes, speed and direction complement each other; therefore assessment of net convergence or divergence becomes more obvious.

Ageostrophic wind component (V_{ag})

- The vector difference between the real (or observed) wind and the geostrophic wind. This difference will be in speed and/or direction.
- The ageostrophic wind represents the “divergent” component of the wind.

Ageostrophic wind component (V_{ag})



Ageostrophic wind component

- Areas where significant ageostrophic wind components exist
  - Regions of strong curvature
    - Produces variations in the gradient wind speed between regions of cyclonic (sub-geostrophic) flow and anti-cyclonic (super-geostrophic) flow (discussed further)

Ageostrophic wind component

- Regions where friction is significant
  - Produces cross-isobar (height contour) flow toward lower pressure (heights) in the PBL. (discussed further)
- Regions where wind is accelerating or decelerating.
  - Produces variations in the actual wind, leading to super-gradient and sub-gradient wind flow. This is common in the vicinity of jet maxes. (discussed further)

Ageostrophic wind component

- Divergence and convergence patterns generated by the ageostrophic wind result in vertical displacements of the air (I.e. vertical motion) which strongly influences cloud development and surface pressure patterns.

Mass Continuity

Mass removed from a region of the atmosphere must be replaced by mass from surrounding areas.

Mass added to a region of the atmosphere must be redistributed to surrounding areas.

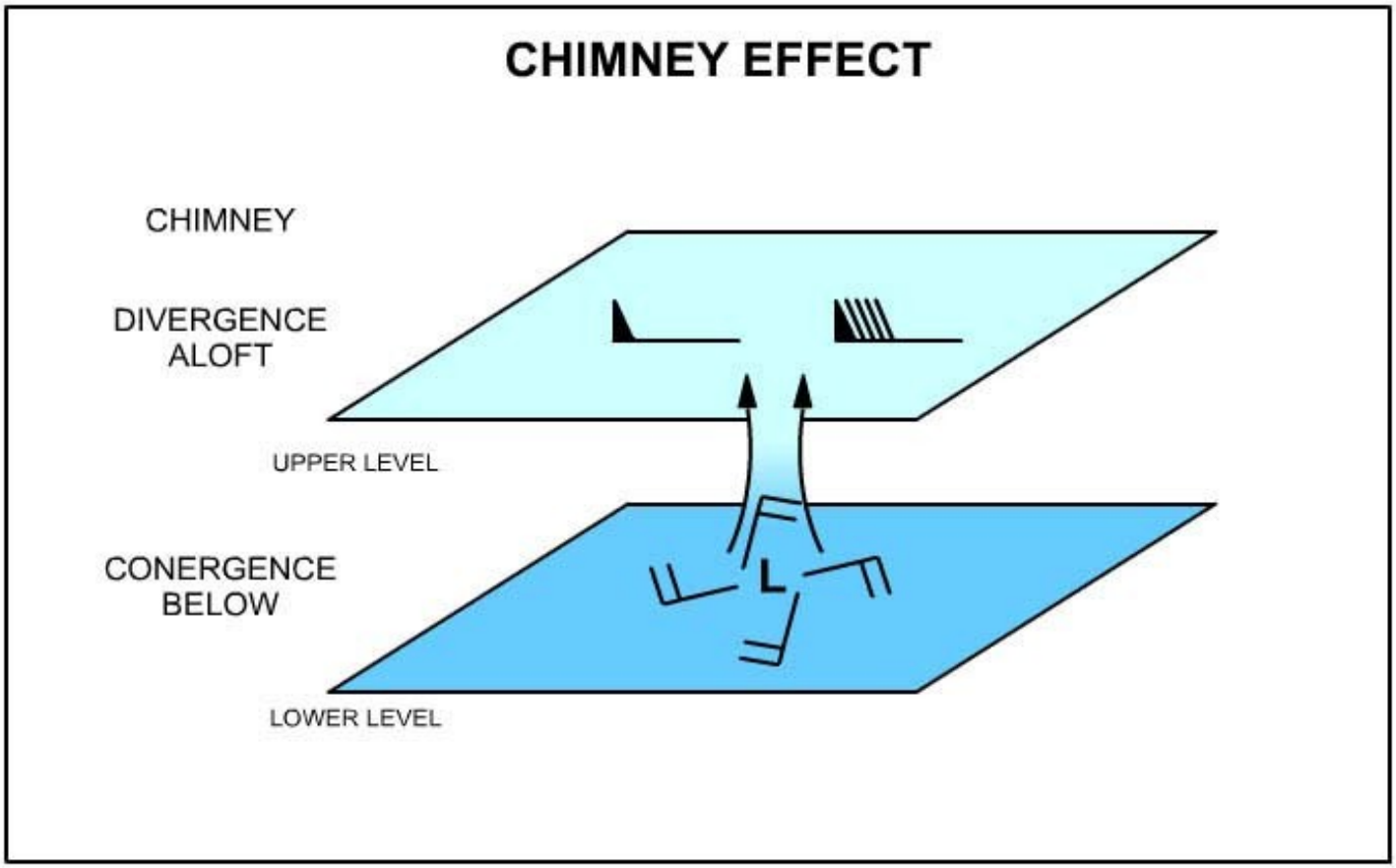
Mass Continuity

- Upper-Tropospheric Divergence (i.e., The Chimney Effect)
  - The removal of mass from the vertical column produces lower pressure at the surface
  - Falling pressure initiates convergence in the lower troposphere.

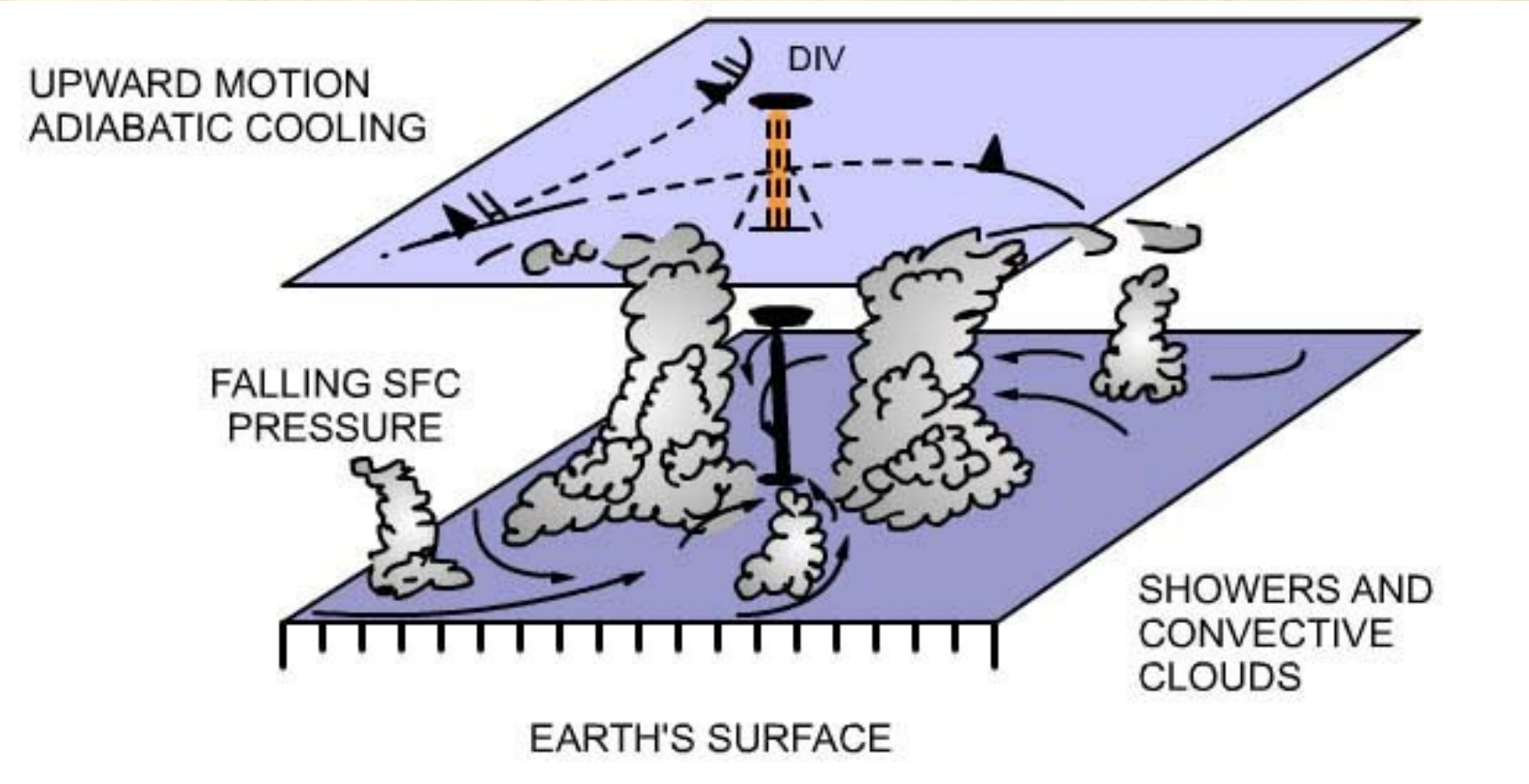
Mass Continuity

– UVM, adiabatic cooling, and possible cloud/storm development and associated deteriorating weather. **as stability changes**

Chimney Effect



Chimney with weather



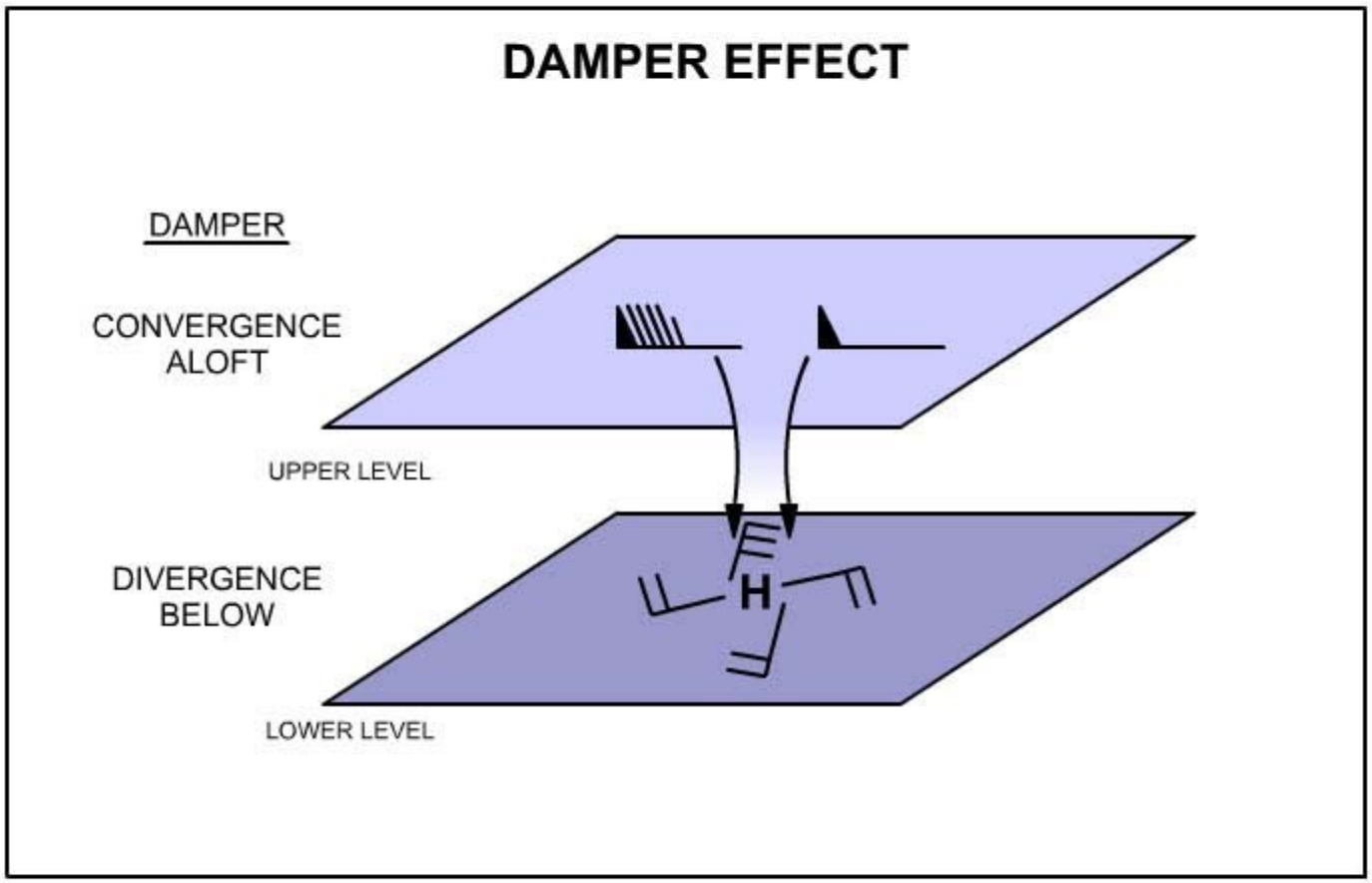
Mass Continuity

- Upper-Tropospheric Convergence (i.e., The Damper Effect)
  - The addition of mass to the vertical column produces higher pressure at the surface.
  - Rising pressure initiates divergence in the lower troposphere.

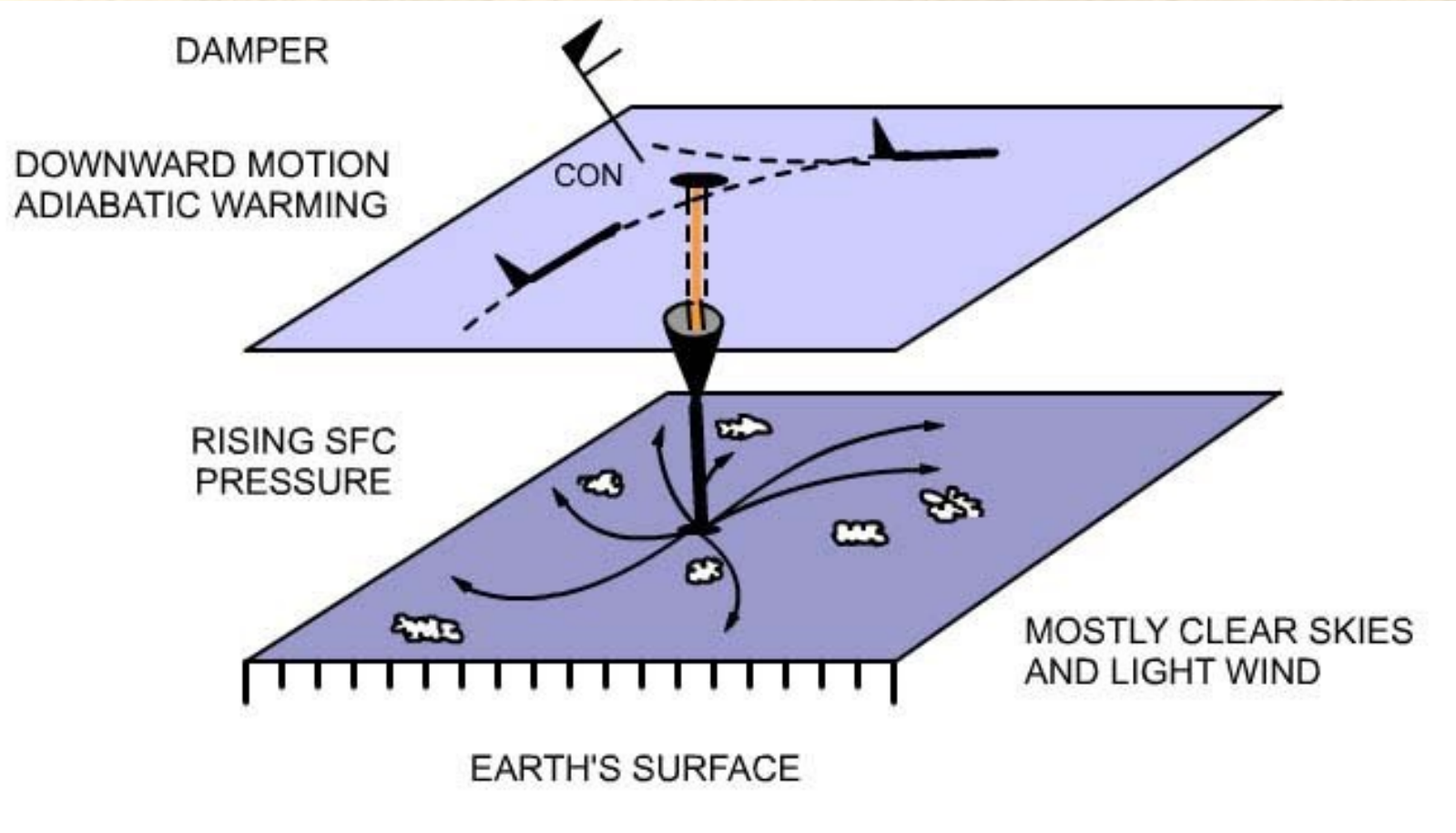
Mass Continuity

- DVM, adiabatic warming, possible cloud/storm dissipation and associated improving weather. **since stability increases**

Damper effect



Damper with weather



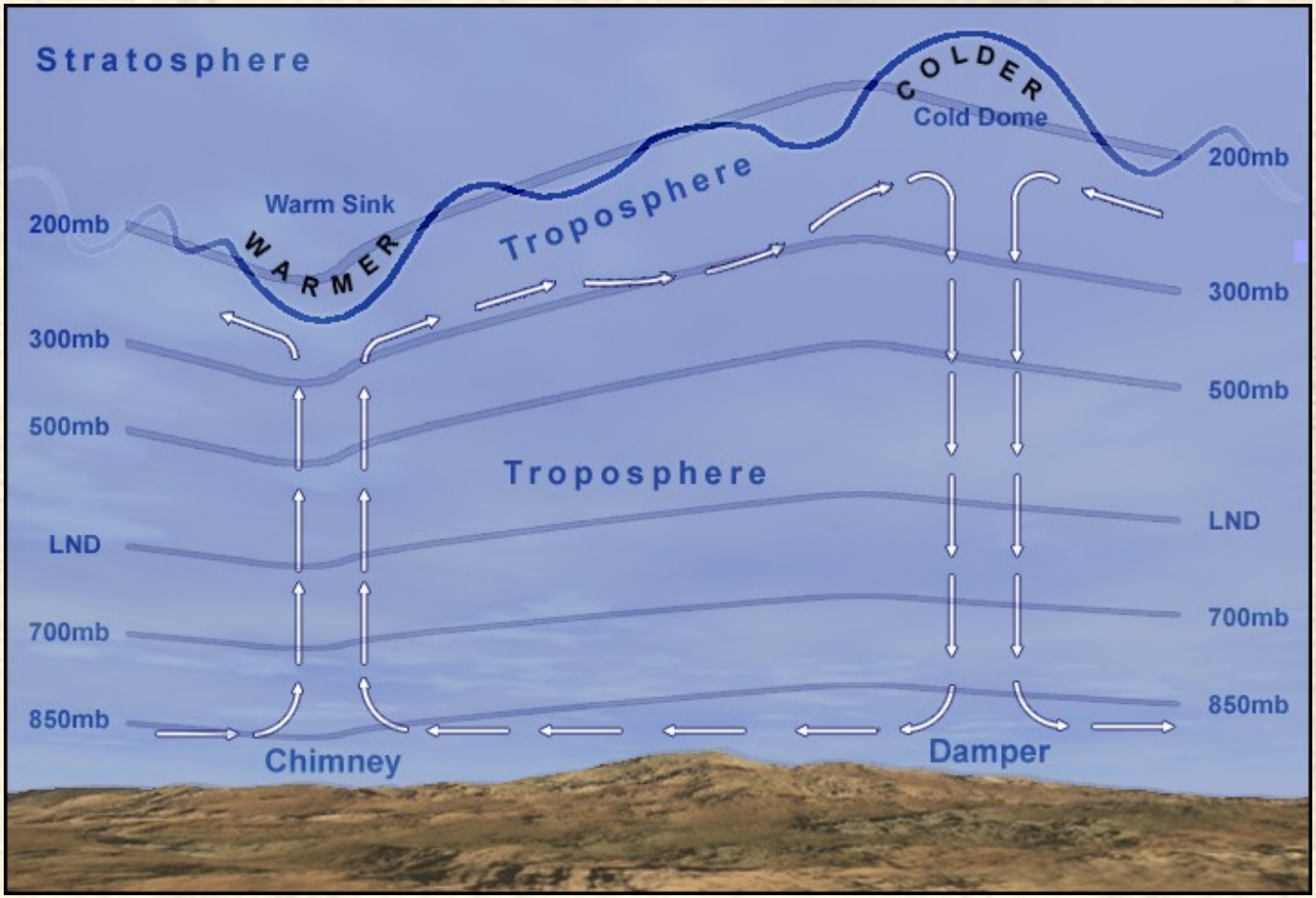
Mass Continuity

- Level of Non-Divergence (LND)
  - Convergence or divergence aloft results in the opposite effect in the lower troposphere
  - There must exist at some level in the atmosphere a Level of Non-Divergence (LND).

LND

- Found under average conditions around 600 mb, but can vary between 700 and 400 mb.
- Marks the level of transition from convergence to divergence or vise/versa.
- Height will be highly variable, based on the atmospheric situation. (Example: found at higher heights as system develops)
- Responsible for steering baroclinic lows and highs.

3-D Chimney and Damper



Processes generating horizontal divergence and convergence.

- Upper levels: the gradient wind relationship produces the divergence and convergence associated with the atmospheric waves.
  - As mentioned before:

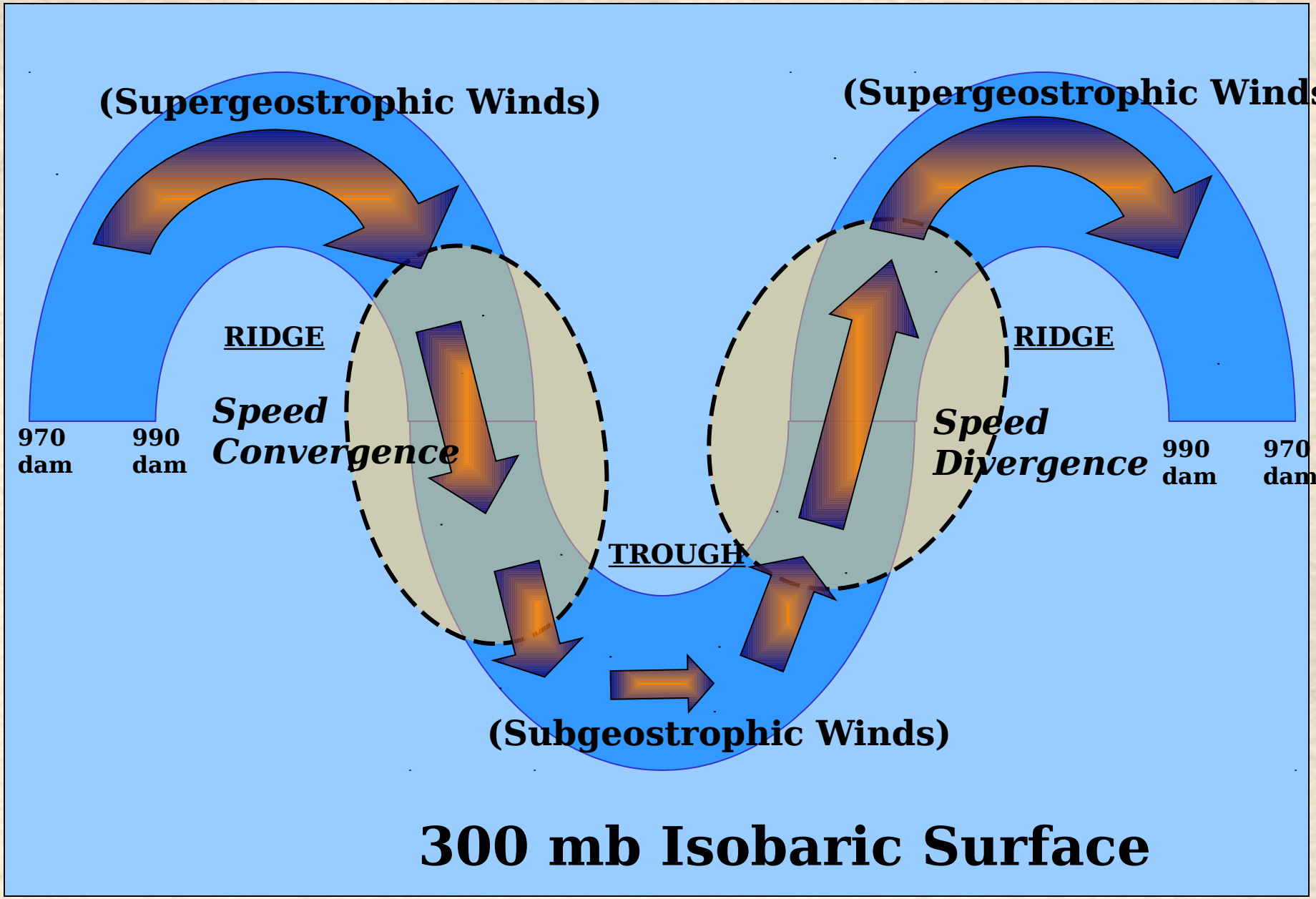
  For the same PG or HG and latitude
    - V_{grad} winds will be stronger in anticyclonic curvature
    - V_{grad} winds will be weaker in cyclonic curvature.
    - **$V_{grad,\ anticyc} > V_g > V_{grad,\ cyc}$**

Processes generating horizontal divergence and convergence

– These super-geostrophic and sub-geostrophic winds develop within cyclonically and anti-cyclonically curved flow around upper-level troughs and ridges, respectively.

Processes generating horizontal divergence and convergence

- These troughs and ridges make up the upper-tropospheric wave pattern within the jet stream. The acceleration and deceleration of the actual winds within this wave pattern generate regions of upper-tropospheric divergence and convergence between upper-level troughs and ridges.
  - Downstream of a trough and upstream of a ridge, the wind undergoes speed divergence as it changes from cyclonic to anticyclonic curvature and undergoes required acceleration from sub-geostrophic to super-geostrophic speeds
  - Upstream of a trough, and downstream of a ridge, the wind undergoes speed convergence as it changes from anticyclonic to cyclonic curvature and undergoes deceleration from super-geostrophic to sub-geostrophic speeds.

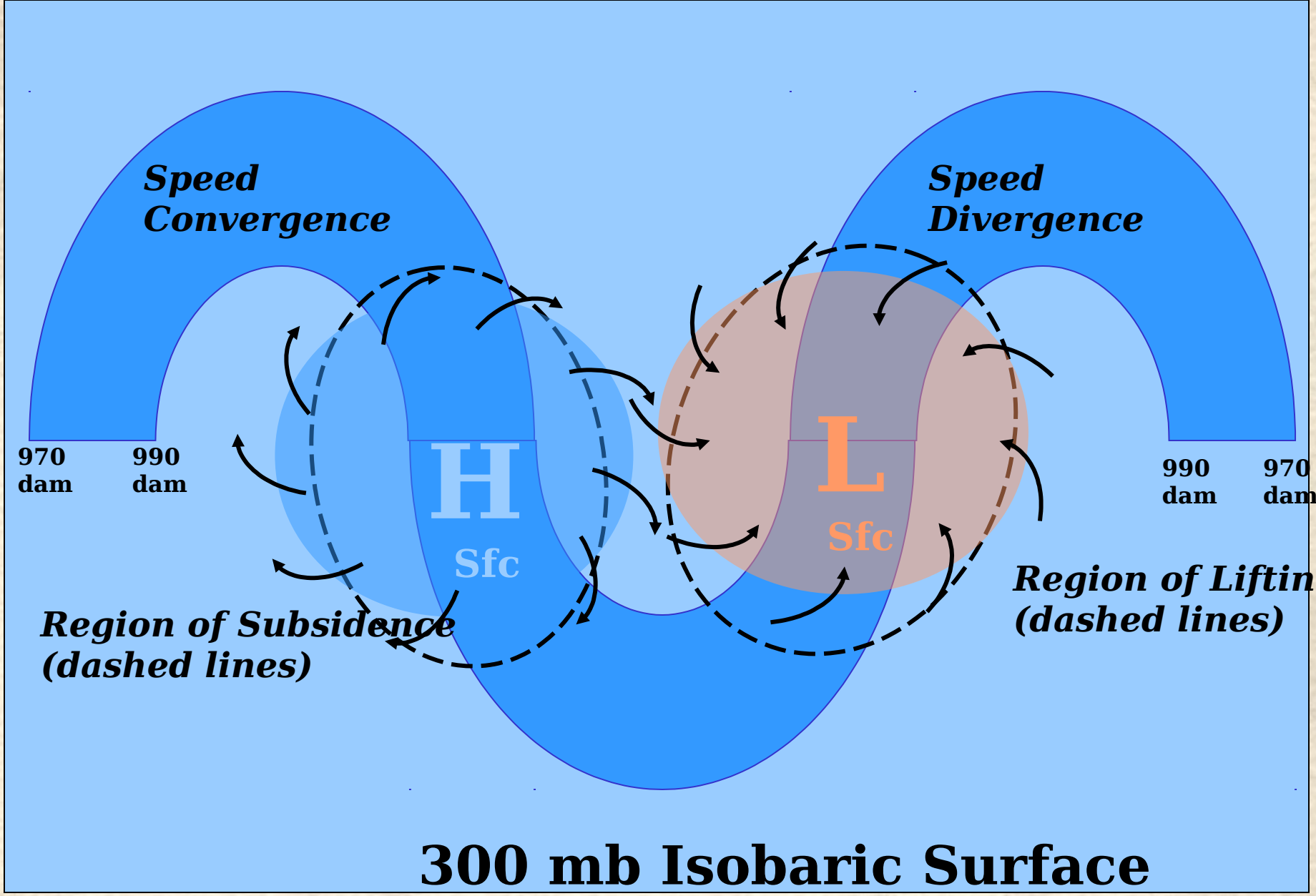

(Supergeostrophic Winds)
(Supergeostrophic Winds)
RIDGE
RIDGE
Speed Convergence
Speed Divergence
970 dam
990 dam
990 dam
970 dam
TROUGH
(Subgeostrophic Winds)
300 mb Isobaric Surface

Processes generating horizontal divergence and convergence

- These convergence and divergence patterns between upper-level troughs and ridges force vertical motion in the mid troposphere and pressure changes at the earth surface.
  - The upper-level divergence downstream of the trough and upstream of the ridge forces:
    - Mid-tropospheric lifting through the LND, generating clouds and possible precipitation.
    - Surface pressure falls, generating regions of low pressure and converging winds.

Processes generating horizontal divergence and convergence

- The upper-level convergence downstream of the ridge and upstream of the trough forces:
  - Mid-tropospheric sinking through the LND, generating clear skies and drier conditions.
  - Surface pressure rises, generating regions of high pressure and diverging winds.


Speed
Convergence
Speed
Divergence
970
dam
990
dam
H
Sfc
L
Sfc
990
dam
970
dam
Region of Subsidence
(dashed lines)
Region of Lifting
(dashed lines)
300 mb Isobaric Surface

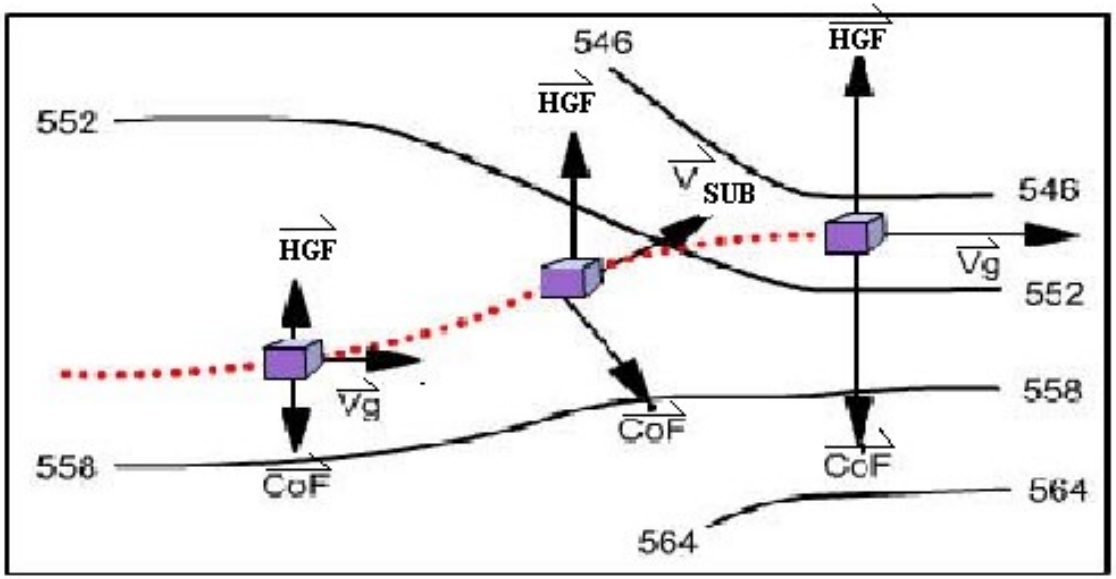
Processes generating horizontal divergence and convergence

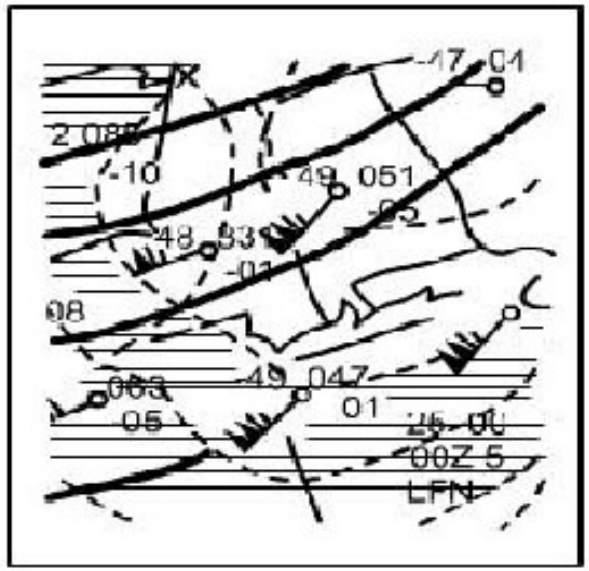
- Jet maxima (i.e., jet streaks) near the tropopause:
  - Strong divergence and convergence patterns are produced by supergradient/subgradient winds near jet stream maxima.
  - These ageostrophic winds and resulting convergence/divergence patterns are produced by changes in the height gradient near jet streaks.

Processes generating horizontal divergence and convergence

- Sub-gradient winds within the jet max entrance region
  - The actual wind is slower (weaker) than the tightening gradient supports

Subgradient vector diagram





Processes generating horizontal divergence and convergence

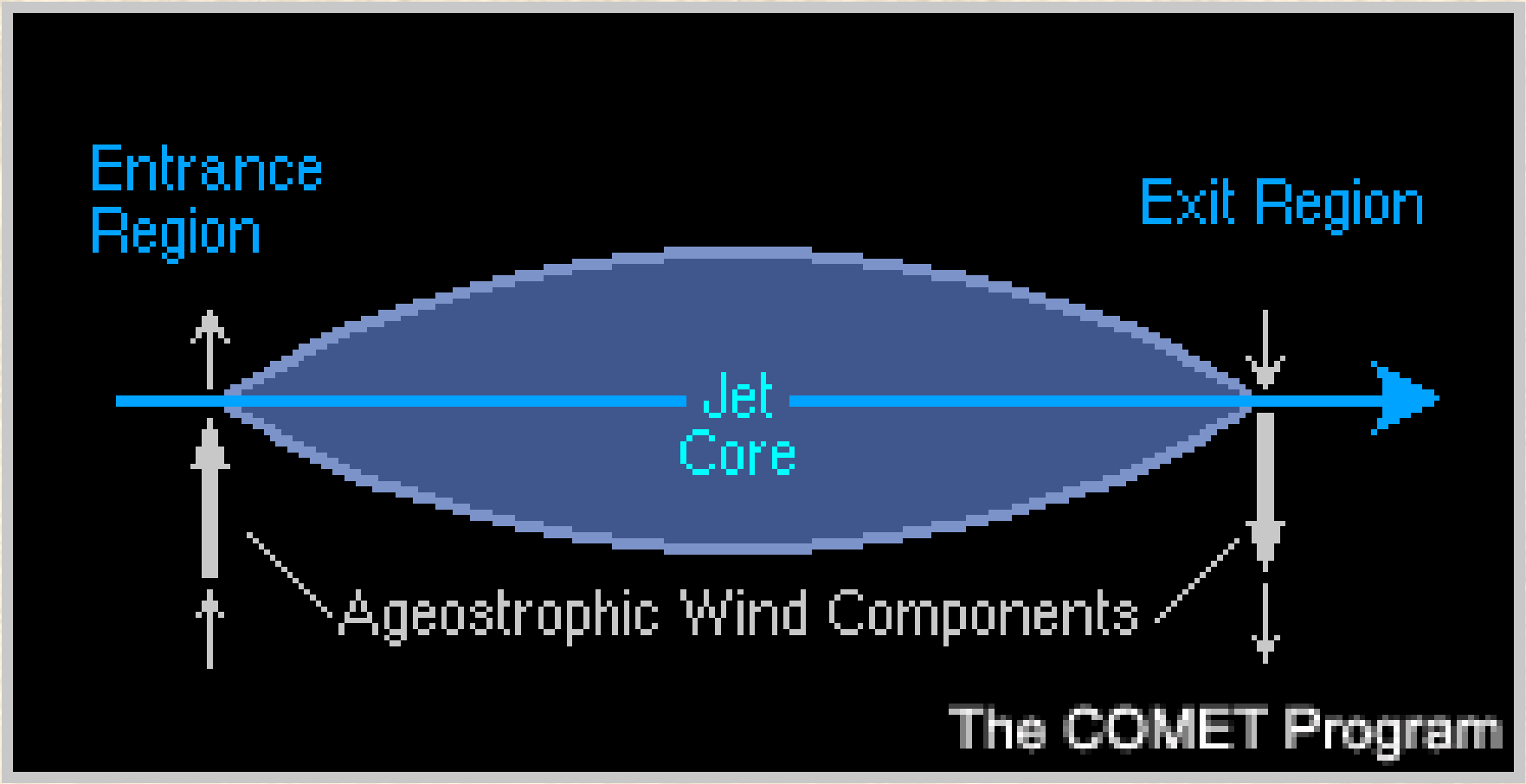
- The jet entrance region is characterized by confluence in the height contour pattern (i.e., downstream tightening of the HG).
- The sub-gradient winds are in the process of speeding up (accelerating)
  - Potential energy is converted to kinetic energy as sub-gradient winds turn downhill and accelerate towards lower heights.
  - ⇓PE = KE

Processes generating horizontal divergence and convergence

- Sub-gradient winds are deflected to the left of gradient flow.
  - HGF increases immediately upon entering the confluent height contour area.
  - HGF becomes stronger than CoF until winds reach gradient wind balance within the core of the jet streak.
  - While the winds are subgradient, they will deflect toward the left, favoring the stronger HGF. HGF and CoF are out of balance. HGF exceeds CoF, thus an ageostrophic wind develops in the HGF direction.

Processes generating horizontal divergence and convergence

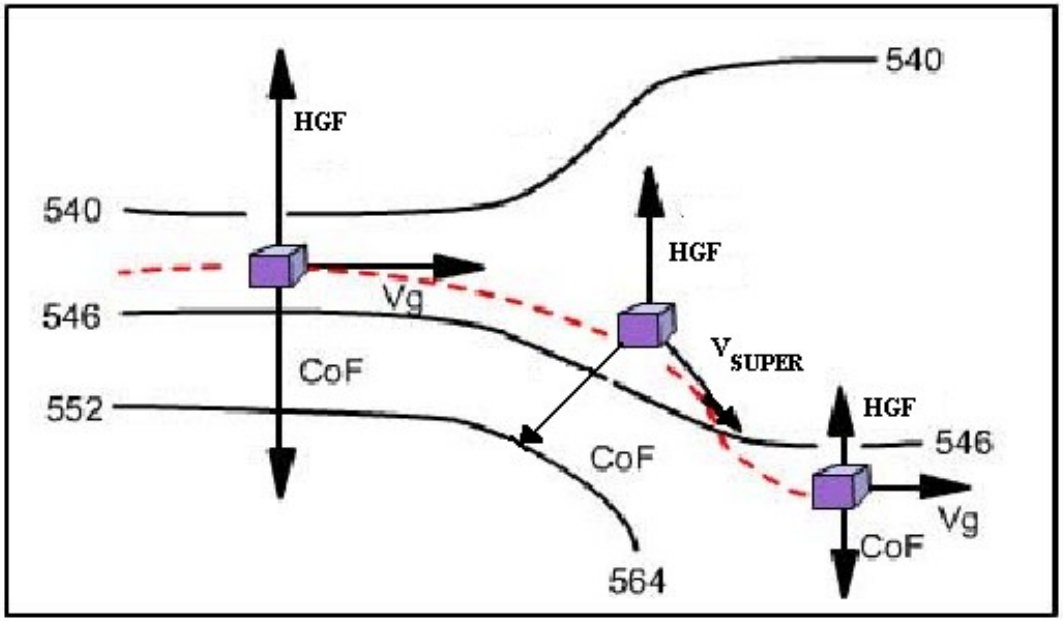
- **This ageostrophic flow toward lower heights (i.e., along HGF) produces a convergence/divergence couplet within the jet entrance region.**
  - » **Mass convergence occurs on the left side of the entrance region, forcing subsidence. A confluent wind pattern often accompanies the convergence there.**
  - » **Mass convergence occurs on the right side of the entrance region, forcing lifting. A diffluent wind pattern often accompanies the divergence there.**
- Example: Entrance region of a jet streak.

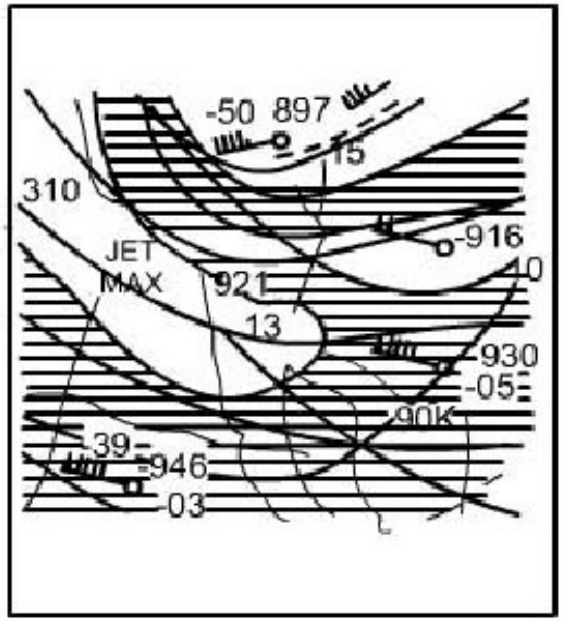

Entrance
Region
Exit Region
Jet
Core
Ageostrophic Wind Components
The COMET Program

Processes generating horizontal divergence and convergence

- Super-gradient winds within jet streak exit region
  - Winds in the jet entrance region are adjusting to a rapid decrease in HGF as they leave a jet streak.
  - The actual wind is faster (stronger) than weakening gradient supports

Supergradient vector diagram





Processes generating horizontal divergence and convergence

- The jet exit region is characterized by diffluence in the height contour pattern (i.e. downstream relaxing of the HG).
- The super-gradient winds are in the process of slowing down (decelerating).
  - » Kinetic energy is converted to potential energy as super-gradient winds turn uphill and decelerate toward higher heights.
  - » PE = KE.

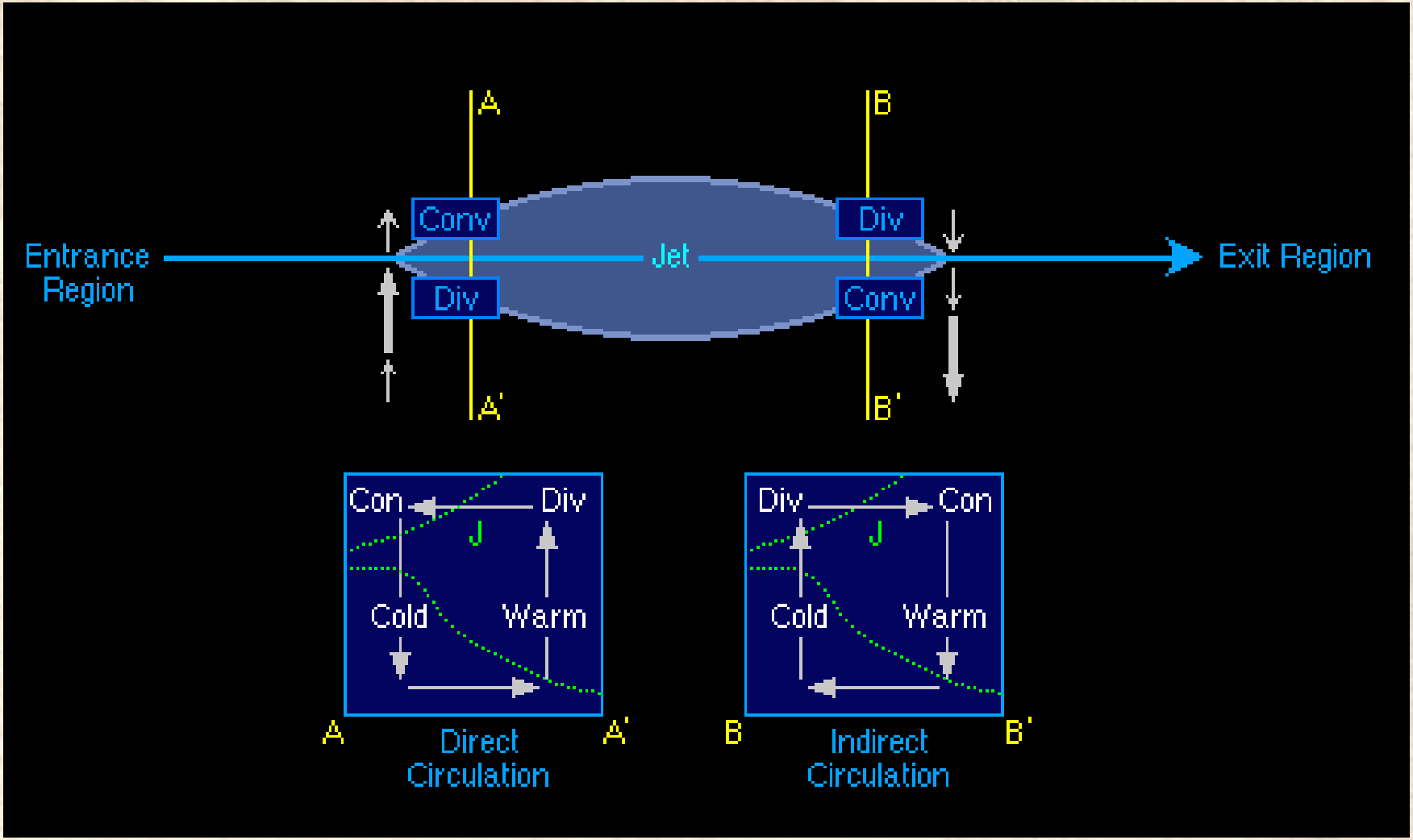
Processes generating horizontal divergence and convergence

- Deflect to the right of motion.
  - » HGF weakens immediately upon entering the diffluent height contour area.
  - » HGF becomes weaker than CoF once winds leave gradient balance in the core of the jet streak.
  - » While the winds are super-gradient, they will deflect toward the right toward higher heights, favoring the stronger CoF. HGF and CoF are out of balance. CoF exceeds HGF, thus an ageostrophic wind develops in the CoF direction.

Processes generating horizontal divergence and convergence

» **This ageostrophic flow toward higher heights (I.e. along CoF) produces convergence/divergence couplet within the jet entrance region.**

» Example: Exit region of a jet streak.


A
B
Conv
Div
Entrance Region
Jet
Exit Region
Div
Conv
A'
B'
Con
Div
J
Cold
Warm
A
A'
Direct Circulation
Div
Con
J
Cold
Warm
B
B'
Indirect Circulation

Processes generating horizontal divergence and convergence

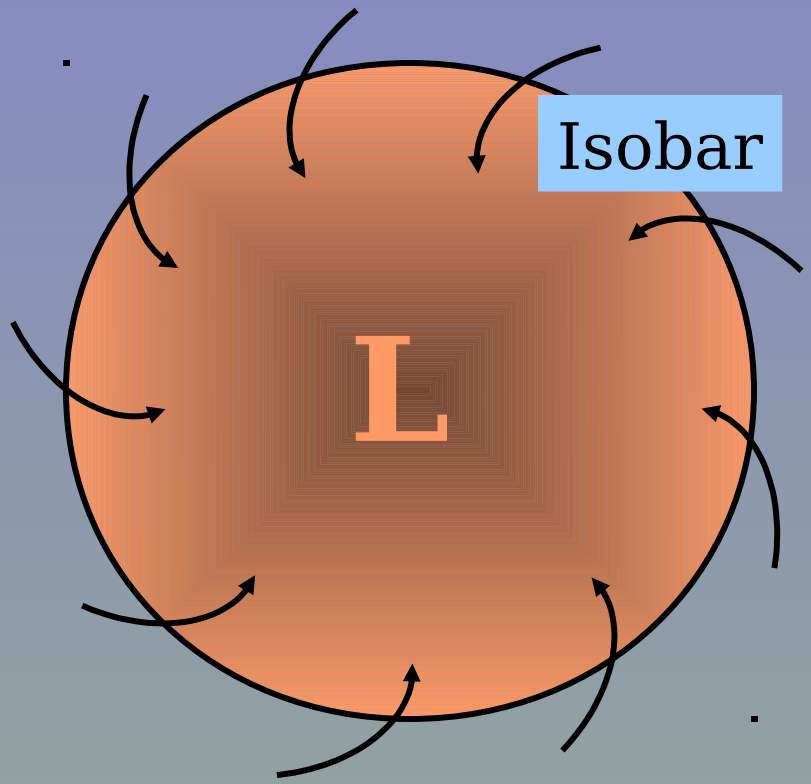
- **NOTE: The above discussion of ageostrophic flow and divergence within jet max entrance and exit regions assumes a straight jet max. In curved jet max patterns, the gradient wind relationship complicates the divergence patterns within jet max entrance and exit regions.**

Processes generating horizontal divergence and convergence

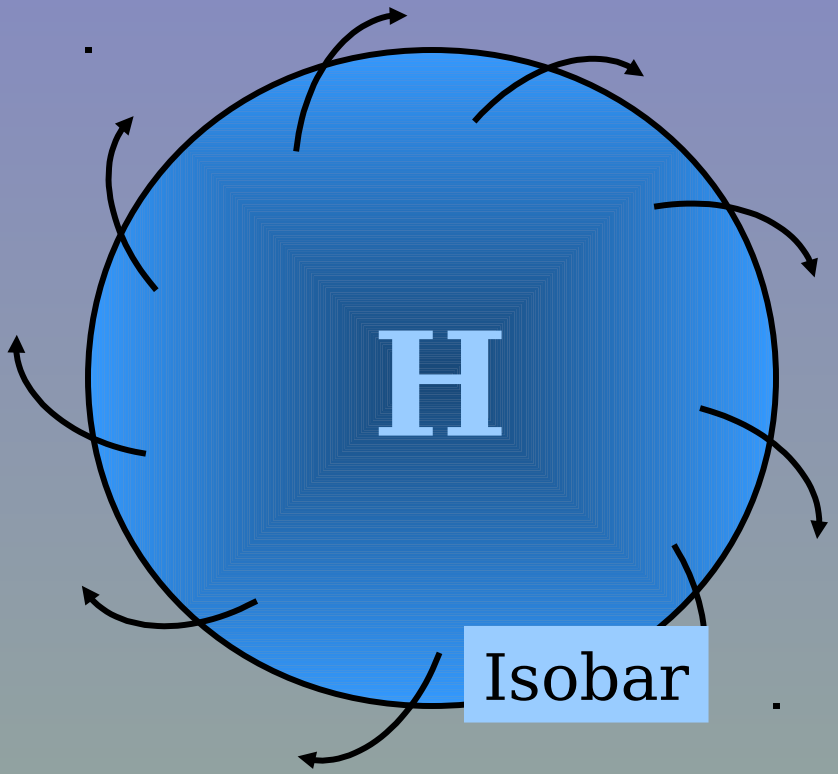
- Low Levels: Frictional effects near the surface.
  - Within the boundary layer, friction disrupts the geostrophic balance of forces, creating an ageostrophic flow and causing winds to cross isobars towards lower pressures (discussed earlier in section b.(13).
  - In cyclonic flow around surface lows, friction induces mass convergence.
    - This near-surface convergence forces lifting of the air.
    - This lifting helps enhance cloudiness and precipitation in the vicinity of surface lows.

Processes generating horizontal divergence and convergence

- In anticyclonic flow around surface highs, friction induces mass divergence.
  - This near-surface divergence forces sinking of the air from above.
  - This sinking helps evaporate cloudiness and aides in the generation of clear dry conditions in the vicinity of surface highs.



Friction induced convergence in cyclonic flow.



Friction induced divergence in anticyclonic flow.

Processes generating horizontal divergence and convergence

- **Results in convergence into the surface lows and divergence out of the surface highs.**

Processes generating horizontal divergence and convergence

- **Upper levels: the gradient wind relationships produce the divergence and convergence associated with the atmospheric waves.**
- **Near the tropopause:**
  - **Strong divergence and convergence patterns are produced by jet stream maxima.**
  - **Discussed in detail in objective g.**

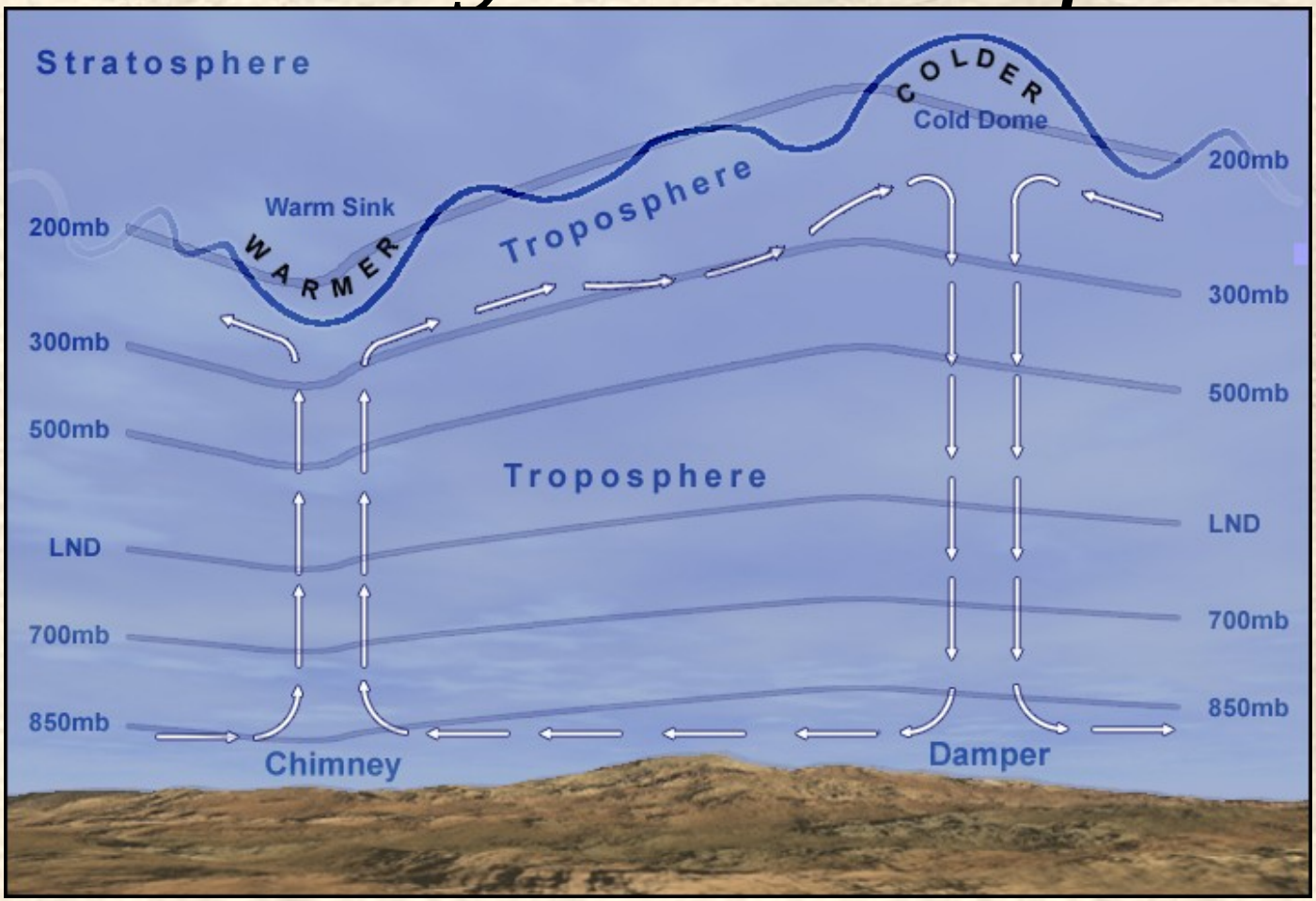
Processes generating horizontal divergence and convergence

- Above the Tropopause:
  - Changes in the height of the troposphere are caused by replacement and displacement of mass,
  - Warm and cold pockets are found above the tropopause in the stratosphere (generally above the **at 200 and** 300-mb level**s**) above areas of strong DIV and CONV.

Processes generating horizontal divergence and convergence

- Warm sinks
  - Warm pockets of stratospheric air evident on the 200-mb chart
  - Found above strong upper level divergence which causes the height of the tropopause to sink with respect to the 200-mb surface.
- Cold domes
  - Cold pockets of tropospheric air evident on the 200-mb chart
  - Found above strong upper level convergence which causes the height of the tropopause to raise with respect to the 200-mb surface.

Vertical cross section Chimney and Damper



- APPLICATION:
- EVALUATION: